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Investigating sustainability assessment methods of product-service systems

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Abstract

Product services systems (PSS) provide a promising opportunity for industries to propose both prosper and eco-friendly solutions to fulfill consumer needs. By shifting from traditional offer, comprised of physical products, to an integrated solution of product and services, it is assumed that PSS may reduce the environmental impact and provide benefits for the PSS provider and the consumer in economic and social ways. However, sustainability is not intrinsic characteristic of PSS. Operational methods and tools are needed to help companies develop such business models and support customer choices relating to PSS contracts. Although there are already well established assessment methods in literature, such as Life Cycle Assessment and Life Cycle Costing, there is still a lack of evidences from the particular field of PSS. Further on, most of existing methods and tools dealing with PSS assessment are based on qualitative parameters, which are subjective and hard to evaluate, and do not provide detailed views of the results. This paper analyses this piece of literature (i.e. relating to PSS assessment) to emphasize similarities and differences between available methods and tools. The aim is to identify the issues underpinning the development of methods for sustainable design in the particular case of PSS.

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Keywords: product services systems (PSS), sustainability, life cycle assessment (LCA).

1. Introduction

Business strategies in the manufacturing sector, focused on increasing productivity became insufficient for companies to remain competitive. There is a shift from providing only physical products to integrated solutions likely to increase market shares and customer satisfaction [1]. This gave rise to a business model aiming "*not to sell goods, but services*" as a solution for the co-existence of business and environment, called Product-Service Systems (PSS) [2].

Product-services systems can be defined as "*product(s) and service(s) combined in a system to deliver required user functionality in a way that reduces the impact on the environment*" [3]. Accordingly, PSS can be seen as a joint answer to increasing customer requirements and sustainability concerns [1,4,5]. Sustainability can be referred to as a system that is economically effective, environmentally sustainable and socially fair [6].

Environmental regulations such as Extended Producer Responsibility, Integrated Product Policy, etc. lead to legal, financial and market constraints on manufacturing industries to produce more sustainable goods (or products) [7]. PSSs have the potential of dealing with this pressure as they aim to fulfil customer needs while meeting sustainability criteria [8]. However, in order to successfully develop and implement PSS, practical methods are needed to support developers, engineers and stakeholders in strategic and operational choices throughout the PSS life cycle. Such practical methods should take into account the sustainability dimensions of the PSS in order to reap its benefits. Subsequently, providing a comprehensive assessment of the PSS sustainability is a key challenge to be dealt with, to develop an entire offer overcoming the sustainability and competition challenges.

In PSS literature, several assessment methods and tools have been developed in order to answer the above question. Accordingly, this paper provides a non-exhaustive state-of-the art of the current PSS sustainability assessment methods in

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order to identify their focuses and limits.
The remainder of the paper is organized as follows; Section 2 provides an overview of the bibliographic research method used within this paper. Section 3 presents the analysis of the identified assessment methods covering each of the sustainability dimensions solely, and sustainability as a whole. Then, findings are discussed in Section 4. Finally, concluding remarks and perspectives for further research are provided in Section 5.

2. Bibliographic research method

The focus of this bibliographic research has been drawn to articles that deal at least with the environmental impact of PSSs. It was also decided to focus on studies that use a life cycle perspective for the evaluation, because it provides a systematic view of the assessment which is of much interest to the PSS context.
A systematic review was conducted using combinations of two keywords relating to two complementary domains : on one side 'sustainability assessment from a life cycle perspective' and on the other side 'Product-Service Systems'. The keywords falling under the first domain are: *life cycle cost, LCC, social assessment, sustainable assessment, environmental assessment, economic assessment, sustainability, performance indicator, life cycle assessment* and *LCA*. While the ones relating to PSSs are: *product service system, servizing, servitization, service economy, functional economy,* and *dematerialization*. The literature review is limited to papers published during the last decade due to the emergence of this thematic.

The keywords combinations were searched in titles, abstracts and keywords of the papers available within searched databases. Around 40 articles were selected out of this research. A deeper analysis of these articles discarded half of them for different reasons (i.e. not relevant to the context of the paper, do not propose assessment methods). Most of the publications were found in *Journal of Cleaner Production* (8 out of 18 articles). The most productive combination is "PSS" and "sustainability", which suggests that these two terms are the most common ones in the analysed piece of literature. The scope of the review was broadened further by including papers referenced by the selected papers. Afterwards a detailed analysis of these papers was carried out and is reported in next sections.

3. Sustainability assessment of PSS

The sustainability of a system cannot be assessed by the use of a single criterion mainly because of the intrinsic multidimensionality characteristic of sustainability. Thus, an evaluation, which considers the three sustainability dimensions, namely economic, environmental and social, is likely to provide more exhaustive sustainability assessment. Therefore, it is necessary to adapt existing indicators (or develop new ones if needed), which are dedicated to sustainability assessment, alongside to characterization factors to translate these indicators, which have different units, into impacts [8]. Indeed, sustainability cannot be defined, neither assessed, only as an addition of its three common dimensions. This means that the common indicators that assess economic, environmental or social domains separately will not approach and assess sustainability in its complexity and wholeness. In spite of this complexity, the analysis of these domains taken separately will surely serve as a basis for the development of a holistic sustainability assessment (Figure 1).

3.1. Life-cycle thinking

Since the shift to PSS is likely to extend the responsibility of the PSS provider to the whole lifetime of the product [9], it is needed to bring the focus of the offer assessment to a life-cycle perspective. Accordingly, more attention has to be paid to some phases that are out of the classical scheme of the relationship between provider and user of the PSS (e.g. take-back, recovery of products and materials, reuse and refurbishment) [9]. Life cycle based approaches, such as Life Cycle Assessment are therefore relevant to the PSS design and assessment.
The 14040 and 14044 ISO standards defined the structure of the LCA methodology and its four phases in details: Goal and scope of the study, Life Cycle Inventory, Life cycle impact assessment and Interpretation [10,11]. The above standards define general guidelines; therefore LCA users have several degrees of freedom allowing them to adapt the method to their specific applications. However, classic LCA based methods may not be suitable for the context of PSS, especially regarding the definition of the functional unit [12]. Indeed, the functional unit is an important basis for system analysis and comparison. Transferring this concept to PSS suggests that functional unit has to describe the functionality of the system including product and service(s), rather than the products (as it is in the classical LCA). The definition of the functional unit is a critical step as it is closely related to the scope definition and thus the results of the assessment. The complexity of defining the scope is heigthtened further by the integration of product and services in the context of PSS. This has implications for the modelling of the processes prior to collecting data and performing the LCA. In fact, the complexity (e.g. allocation of the impacts to actors of the value chain) and heteroegneity (tangible vs. intangible) of the assessment inputs call for proper modelling of the PSS in order to easily derive scope definition of the PSS assessment.

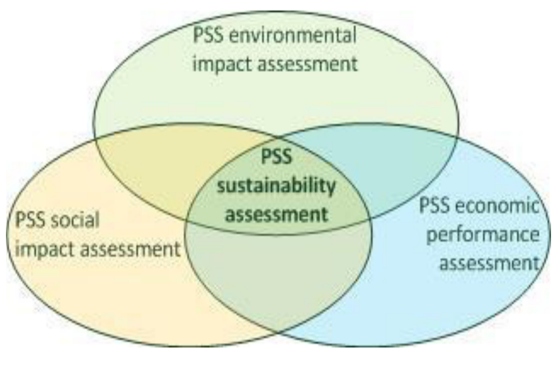

Figure 1: Scope of the investigation

3.2. Environmental impact assessment

Current literature investigation shows that methods used to assess the environmental impact of PSS are not the ones widely used and agreed upon within LCA community (e.g. ILCD 2011 and Recipe). This could be partially explained by the fact that the interpretation of the result of these methods is not straightforward for non-LCA-specialists. Commonly used methods in the context of PSS are, Eco-Indicator 99 [12–15] and Environmental Improvement Made Easy method (EIME) [16,17] (summarized in table 2). The Eco-Indicator 99 method is widely used by designers in many industries [18] however this method was replaced by the ReCiPe method which is an integrated update of Eco-Indicator 99 and CML.. In this method, environmental assessment relies on three comprehensive damage categories, namely Human Health, Ecosystem Quality, and Resources. The peculiarity of the Eco-Indicator 99 method is that it offers the possibility to aggregate the results into a single score, thus providing a comprehensive overview of the evaluation. As such, the results can also be used for reporting purposes. This aggregation may however not be particularly relevant to decision makers because it introduces a value judgement which can influence the results and conclusions of the LCA [19].

The EIME framework (which includes a software tool, a database and an assessment method) was developed for the electronic industry in order to reinforce the applicability of the LCA standards in this specific sector. Thus, EIME database stands as a reference in the electronic industry [16]. The EIME software tool is based on the LCA methodology consistently with the 14040 and 14044 ISO standards.

Lindahl [14] studied the PSS offers of three case-companies (core plugs for paper mills, cleaning walls and compacting soil) by using the Eco-indicator 99 method. For each of the three case companies, two alternatives are assumed to be available in the current market, i.e. one sales offer and one PSS offer. Another prospective alternative consists of a mix of traditional (i.e. sales) and PSS offers. Afterwards, Lindahl [14] proposed a relative result that is calculated in percentage to make it understandable by non-LCA-specialists. Similarly, Cor et al. [13], Shih et al. [15], and Amaya et al. [12] used the Eco-Indicator 99 method, but their results totally differ from Lindhal [14] in terms of presentation. Further, Shih et al. [15] present the relative environmental impact of the life cycle’s steps of the product (e.g. Use, Distribution, etc.) for each category (e.g. Greenhouse gases, Acidification, etc.) while Cor et al. [13] and Amaya et al. [12] only consider the single score calculated by the method. In the case study reported by Lelah et al. [16] the results of an EIME based-tool are structured according to the impact categories (e.g. Global Warming Potential, Ozone Depletion Potential), consistently with the product life cycle phases (e.g. use, installation, manufacturing, etc.).

Eco-Indicator 99 and EIME methods provide quantitative results, thus facilitating the analysis. However, major issue underlying these methods relates to detailing the results. In fact, indicators are aggregated in order to provide comprehensive results for non-LCA specialists, which leads to a lack of completeness of the results.

In summary, the methods used to assess the environmental impact of PSS are basically quantitative. Additionally, they are not the commonly used by the LCA-community since the main criteria for selecting them for the PSS context, is the ability to provide comprehensive and synthesised results. Accordingly, these methods facilitate results sharing through aggregating measures into a limited number of indicators. This may, however, influence the conclusions of the analyses because of biased results.

In most of the reported case studies, the assessment provides relative results, relying on comparative analyses of different scenarios. This characteristic is well suited for the design process of PSSs, where different offer alternatives are compared to come up with the most viable ones.

Table 1 : summary of the methods and indicators analyzed

Application	Indicators (method)	References
Cleaning walls, core plugs, compacting soil	Ecopoint (Eco-indicator 99)	[14]
Coffee maker	Ecopoint (Eco-indicator 99)	[13]
Bike sharing	Ecopoint (Eco-indicator 99)	[12]
Mop rental service	greenhouse effect, ozone layer depletion, acidification, eutrophication, heavy metals, carcinogenity, winter smog, summer smog and pesticides impact groups (Eco-indicator 99)	[15]
Waste glass collection	Energy depletion, global warming, air toxicity, water toxicity, raw material depletion, hazardous waste production (EIME)	[16]
Municipal waste collection	raw material depletion, global warming (EIME)	[17]

3.3. Economic performance assessment

The economic assessment is a critical step in the implementation of a PSS-offer. It seems logical that a company will not adopt this type of business model if it is not prosper, regardless of the potential benefits in terms of social and environmental impacts. Similarly, from the customer point of view, purchasing or renting cost is a major criterion impacting on the decision making process. However, customers are basically focused on the initial PSS cost and tends to disregard other incurred costs throughout the use and end of life phases [20]. Therefore, economic assessment has to be as accurate as possible in order to reduce uncertainty in the decision making both on the side of PSS provider and customer.

Narrowing the research scope to life cycle thinking assessment, current review shows that Life-Cycle Cost (LCC) is among the most commonly used methods in the context of PSS [9,14,15,20–22]. Generally, LCC is divided into five phases: material processing, manufacturing, distribution, use, and disposal cost. These breakdowns are used to identify costs incurred by different PSS stakeholders [15]. Lindahl and al.

[14] stick to the relative comparative result between the different alternatives. Therefore, it is not possible for Lindahl approach to assess to which phase of the life cycle the gain is located. Mannweiler et al. [20], for instance, discuss the necessity of the development of an indicator taking into account these costs so as to evaluate and select the suitable PSS.

In brief, it could be said that there is a need for PSS economic performance assessment to both PSS provider and customer. For now, life-cycle cost (LCC) is commonly used in the context of PSS, consistently with the life cycle perspective. This method assesses the cost throughout the lifetime of the offer. However, it fails short of showing the changes occurring in the business model resulting from the shift to PSSs. In fact, both PSS provider and customer need to be informed of the structure of costs and revenues lead by the servitization process. The ultimate objective is to develop a PSS offer from a win-win perspective. The economic assessment should thus be detailed enough to provide a useful support to the PSS design process. It is challenged however, by the lack and uncertainty underlying the data at this early stage of the PSS development.

3.4. Social impact assessment

The social dimension has been receiving little attention for decades [8,23]. Halme et al [23] argue that this may be one of the reasons why sustainable product-service systems have not experienced the expected success. The social dimension of the sustainability is the most difficult dimension to assess for multiple reasons. As the producer becomes more responsible of its product, he has to strengthen his ability to cooperate with the customers [8]. The social assessment must try to evaluate this relationship, but also relationships with other stakeholders (employees, local communities, suppliers) [24]. The difficulty of this assessment pertains to the fact that relationship between these stakeholders cannot be quantified using quantitative indicators such as production costs or water consumption for instance.

The emerging integration of all three sustainability dimensions shed more light on social assessment. Accordingly, Omann [24] introduced criteria such as gender, opportunities, health and justice. The evaluation is done thanks to questions translating the changes between the traditional business offer and the PSS offer. Later on, these are scored by subject, and finally aggregated (through weighting) so as to obtain a *social score*. Other authors also used the concept of a unique score and used surveys along with some quantitative indicators. As an example, Abramovici et al. [25] assess the *job opportunities* based on the amount of working hours allocated to the PSS. They also integrated the evaluation of a data quality indicator, in order to be aware of the subjectivity of particular indicators. Although data quality is still an issue in most assessment methods, it remains even more challenging when it comes to social dimension of sustainability. For example, in the case studies reported in [25] , 3 out of the 4 indicators (*employee satisfaction, job opportunities and service creation)* of the social dimension have a low-quality data coefficient, meaning that the data is coming from open source databases and/or not specific enough to the analysed process.

In summary, it exists clearly a lack of quantitative assessment of social impact of PSS. This can be explained by the high uncertainty and subjectivity of the social aspects resulting into qualitative assessment. In literatures, there are some attempts aiming to translate the social impact through indicators (such as working hours or percentage of women workers) but they are difficult to aggregate and most importantly, cannot be easily characterized using predefined factors. This calls for further research to develop method for assessing the social impact and to integrate it into sustainability assessment of PSSs.

3.5. Sustainability

Abramovici et al. [25] introduced an approach to assess the sustainability of a system as a unique criterion based on an average of the economic, environmental, social and PSS-specific performance. Nonetheless, assessing sustainability in this way may lead to bad interpretations because this method implies that all pillars are equally weighted. For instance, decreasing the environmental impact can compensate an increase of social impact. In fact, in this evaluation the percentage of recycling parts has the same weight in the evaluation than the CO_2 emission or the employee training. There is also another weakness underlined by the 'rebound effect'. For example, the use of information technology solutions instead of hiring people may increase the economic output, but is likely to worsen the environmental and social impacts. In the same sense, Partidario et al. [26] figured out, when investing in an integrated food service, that the solutions decrease significantly the energy consumption while increasing both material consumed and waste production. Moreover, in [26], integrated food service may lead the elderly to have fewer personal contacts, which may be not profitable for their social life. Halme et al. [23] proposed a tool and a set of indicators to evaluate the sustainability of services provided to households. They found out that social benefits are greater than the environmental and economic ones. Furthermore, this study gainsays a common assumption that services lead to reduced material use.

4. **Summary and discussion**

From the above analysis, it can be stated that the assessment of PSS is more established according to environmental and economic views than the social view. The environmental assessment, based on the ISO standards (14040 and 14044), is the most discussed in the literature with the aim of mitigating uncertainty about the potential benefits that PSS may provide to the environment. Some studies warn about the rebound effect of PSS or about the use of information technology (IT) that may decrease some impacts while increasing other ones. Although economic assessment is not based on standards such as LCA for example, it does not mean that the studies are not rigorous. The higher purchasing cost of PSS is one of the barriers because often the customers are not aware of the hidden costs throughout product life cycle, in particular during use and end of life phases. Under these circumstances, the evaluation of the total cost of an offer throughout its whole life is important to inform the consumer about the hidden costs as well as the provider about the economic performance of the PSS. Furthermore, the social dimension is rarely studied as it involves various stakeholders in the assessment process and often concerned with their interrelationship, which is subjective by nature and context-dependent.

Holistic sustainability indicators improve the readability of the assessment results for both PSS stakeholders and non-expert users. This however adds some biases that is, judgement and shortcuts which may lead to wrong conclusions and poor decisions. Nevertheless, it is important to consider sustainability as a whole in order to avoid damaging one dimension while limiting harm made to another one. Additionally, some other aspects may be taken into account, such as the PSS-operational performance. This would allow comparing scenarios at different granularity levels and time horizons. Beyond applying existing assessment tools (e.g. LCA, LCC) to the PSS context, it is needed to propose proper assessment methods that should be integrated in the early design stages. This would facilitate identifying trade-offs between various concerns of the stakeholders involved in the PSS.

Alongside with proper assessment methods, the PSS should be easily configurable so as to meet as many customer requirements as possible. This calls for concepts such as modular products, and even further, modular PSS offers. The modularity should then be taken into account by any assessment method intended to foster both sustainability and customer satisfaction of the offered PSS solutions. Another challenge that needs to be met, relates to the estimation of data about use phase, since the early design stages. Finally, change in business model induced by the shift to PSS implies change in institution arrangement which can impacts on economic, environmental and social dimensions of sustainability of manufacturing companies. All this will, of course, need a work on the integration of the social dimension as well as a deeper estimation of the uncertainty due to *a priori* context but also because of the lack of data about the effective lifecycle of the offer.

5. Conclusion and perspectives for researches

PSS is shown as one of the solutions for companies to maintain their competitiveness while overcoming the sustainability challenge. The potential of PSS to leverage sustainability is obvious. Nonetheless, PSS may lead to increase environmental impact or decrease social interactions under certain circumstances. Therefore, the design of PSS is a critical step which requires methods and tools to guide stakeholders of the PSS throughout a life cycle perspective. Finally, there is still a gap between the design and evaluation phases of the PSS development process. Such gap could be filled out by developing multi-level methods to enable practitioners to assess the impact (in terms of sustainability) of their choices at different stages of the design process. A first support can be provided at the very beginning of the design process and which involves the functional analysis. The aim here is to extend the scope of the technical solutions to services and not only physical products. Another support can be provided at later stages and is concerned with the configuration of the value chain delivering the PSS to the market. As such, the intended support could help industrials overcome sustainability and competition challenges.

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